# Semi Annual Report

(January 1 — June 30, 2003)

Contract Number NAS5—31363

# OCEAN OBSERVATIONS WITH EOS/MODIS:

## Algorithm Development and Post Launch Studies

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# Preamble

This document describes our progress thus far toward completion of our research plans regarding two MODIS Ocean-related algorithms.

A. Retrieval of the Normalized Water-Leaving Radiance (Atmospheric Correction).
B. Retrieval of the Detached Coccolith/Calcite Concentration

In addition, we break our effort into two broad components for each algorithm:

- Algorithm Improvement/Enhancement;

- Validation of MODIS Algorithms and Products.

These components will overlap in some instances.

# RETREIVAL OF NORMALIZED WATER-LEAVING RADIANCE (ATMOSPHERIC CORRECTION)

## Algorithm Improvement/Enhancement

### *1. Evaluation/Tuning of Algorithm Performance*

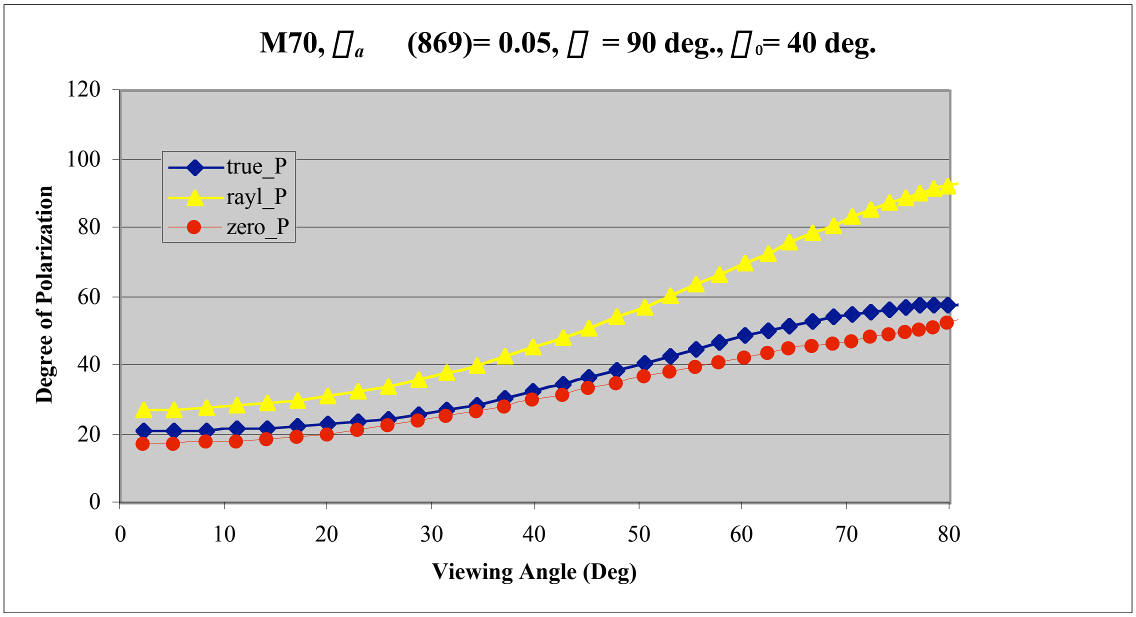
Task Progress:

As indicated in our last Semiannual Report, considerable effort has been expended by R. Evans and co-workers toward removing the instrumental artifacts from Terra/MODIS ocean imagery. Examples of such artifacts are severe striping, mirror side differences, effects of the variation of the instruments response as a function of scan angle, and the influence of instrumental polarization sensitivity. Sufficient progress has been made along these lines that MODAPS has begun the first retrospective reprocessing of Terra/MODIS ocean data.

During this reporting period, examination of the Miami RADCOR (end-stage radiance calibration adjustments to each MODIS band made by R. Evans by direct comparison with MOBY) files showed that there was an apparent yearly oscillation in the calibration adjustments that in some bands reached 4% (peak-to-peak) but was typically closer to 2%. Possible explanations for this behavior are, an error in the atmospheric correction processing algorithm code, incomplete correction for the MODIS polarization sensitivity, and an error in the MODIS L1A calibration.

To try to understand the source of the RADCOR file's temporal behavior our group along with R. Evans' group undertook a full examination of the MODIS L2 processing code. The result was that an error (suggested by Bryan Franz) was found and corrected in the sun glint code, and the sun glint code was enhanced by including the polarization of the surface-reflected sunlight in the polarization-sensitivity correction algorithm.

We wanted to see if it was possible that a poor polarization correction at the MOBY site could be the cause of the strange RADCOR behavior. The affects of polarization sensitivity were originally corrected, following Gordon, Du, and Zhang ["Atmospheric Correction of Ocean Color Sensors: Analysis of the Effects of Residual Instrument Polarization Sensitivity," *Applied Optics*, **36**, 6938-6948 (1997).], by assuming that the total radiance at the sensor was polarized in a manner identical to Rayleigh scattering. However, this was later improved by assuming that only the Rayleigh component of the radiance was polarized. The efficacy of this approach is provided in Figure 1 for the M70 aerosol model that is close to the aerosol extant much of the time at the MOBY calibration site. For the optical depths ($\tau_a$) typical of those at the



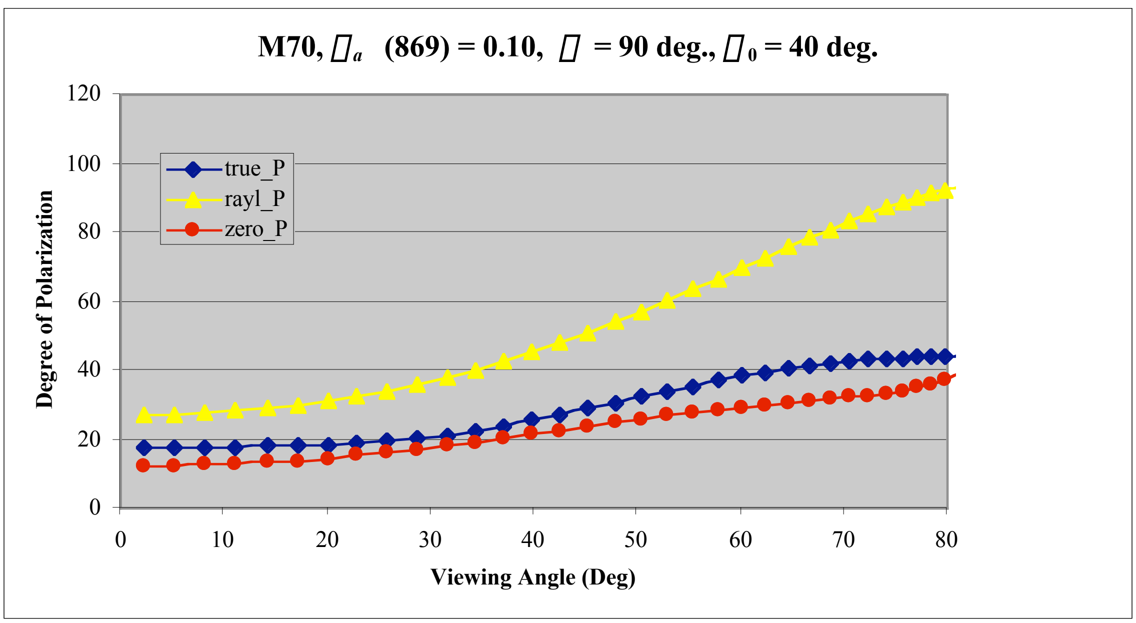




Figure 1. Two examples of the degree of polarization of the top-of-atmosphere (TOA) radiance. The "true_P" curves are the computed by taking into account all processes leading to polarization, the "rayl_P" is the polarization that would be seen in a pure Rayleigh-scattering atmosphere, and "zero_P" is the approximation used in the present MODIS algorithm

MOBY site we see that assuming the radiance is polarized as Rayleigh scattering greatly overestimates the degree of polarization, while the present approach, "zero_P," provides an excellent approximation to the actual polarization of the TOA radiance. Thus, with the proviso that the MODIS pre-launch polarization characterization is reasonably accurate, a polarization-sensitivity correction error is probably not the cause of the RADCOR behavior.

As mentioned above, we completely reexamined the sun glitter code correcting an error (that had no affect on the RADCOR issue). It is perhaps appropriate at this time to discuss some of the problems regarding the sun glitter problem. The basic formulation of the glitter relies on the work of Cox and Munk [Measurements of the Roughness of the Sea Surface from Photographs of the Sun's Glitter, *Jour. Opt. Soc. of Am.* **44**, 838--850 (1954)]. In particular, Cox and Munk related the upwind and crosswind slope variances $s_u^2$ and $s_c^2$ to the wind speed $W$ according to

$$s_u^2 = 0.000 + 3.16 \times 10^{-3}\, W \quad \text{and} \quad s_c^2 = 0.003 + 1.92 \times 10^{-3}\, W.$$

However, Shaw and Churnside [Scanning-laser glint measurements of sea-surface slope statistics, *Applied Optics*, **36**, 4202-4213 (1997)] reported strong dependence of the $s_u^2$ and $s_c^2$ relationship to the wind speed $W$ on the atmospheric stability. Near neutral stability, the upwind variance was ~ 40% greater than the Cox and Munk values that were likely derived under conditions of positive stability (cold water under warm air). Also, under conditions of strong negative stability (more characteristic of much of the ocean), the deviation from Cox and Munk was even larger. In contrast, Ebuchi and Kizu [Probability distribution of surface wave slope derived using sun glitter images from geostationary meteorological satellite and surface vector winds from scatterometers, *Jour. of Oceanogr.*, **55**, 477-486 (2002)] used actual glitter patterns from geostationary satellites and actual winds from scatterometers to derive $s_u^2$ and $s_c^2$ directly. They found a much smaller dependence of $s_u^2$ on $W$ than Cox and Munk, suggesting that the satellite measurements were made under conditions where the wind and waves were likely to be in equilibrium, contrasted to Cox and Munk where the waves were likely to be growing. Thus we have two recent studies coming to opposite conclusions: Shaw and Churnside suggesting that the Cox-Munk $s_u^2$ is *too small*; and the Ebuchi and Kizu suggesting that the Cox-Munk $s_u^2$ is *too large*. The inescapable conclusion is that both of these studies are correct: $s_u^2$ is dependent on more than just the wind speed, i.e., atmospheric stability and the departure from equilibrium between the wind and the wave field. It may even depend on other quantities yet to be identified. It is truly remarkable that the MODIS sun glint correction performs as well as it does!

In our search for possible problem in the MODIS atmospheric correction code, we also examined the aerosol model choices made by the correction module, after noting that there was a strong seasonality in the model choices. Such seasonality is clearly evident in Figure 2 which provides the model choices as a function of time over a three-year period.

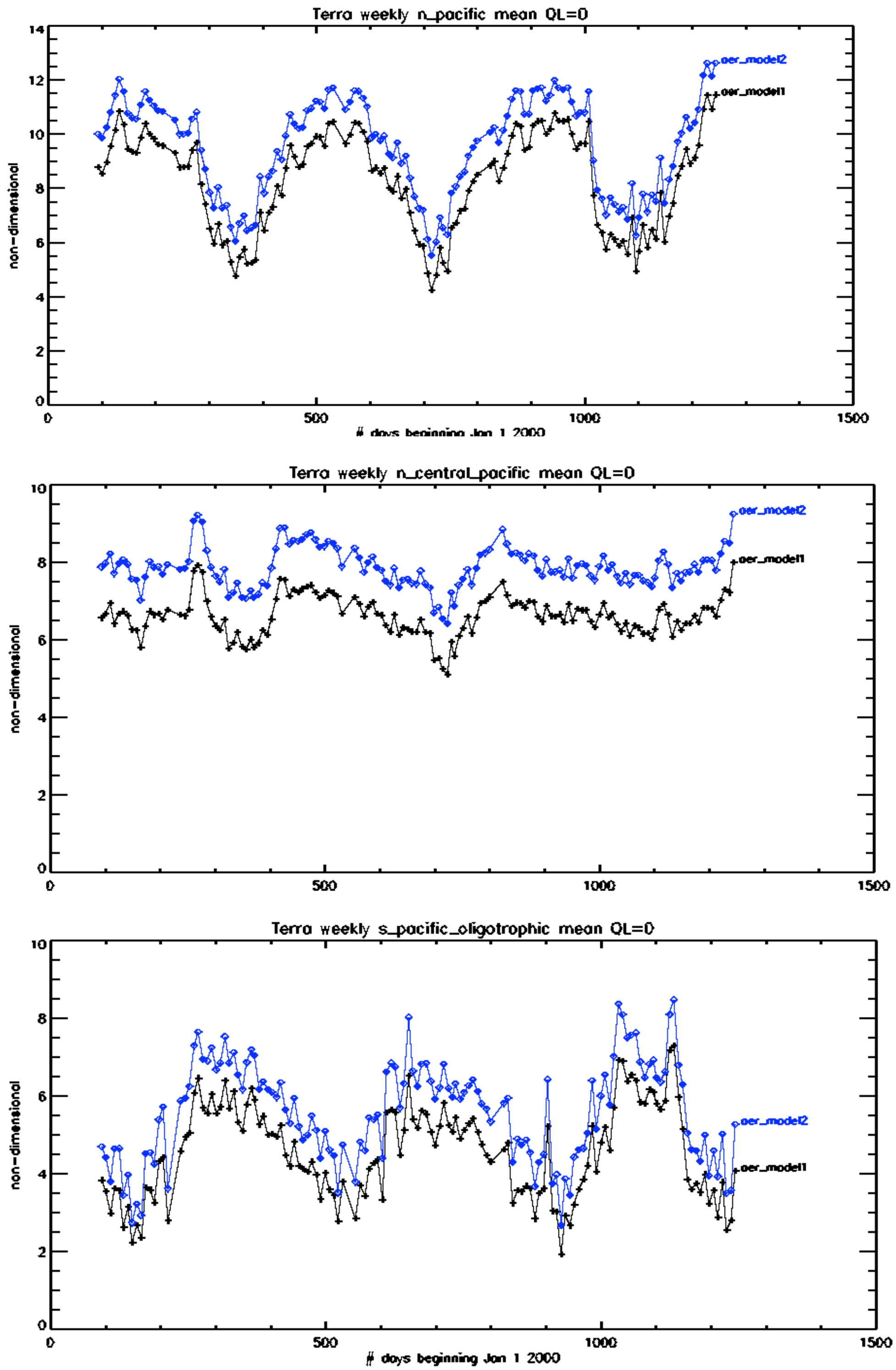



Figure 2: Aerosol models chosen by MODIS Terra in the North Pacific (top), Equatorial Pacific (center) and South Pacific (bottom).

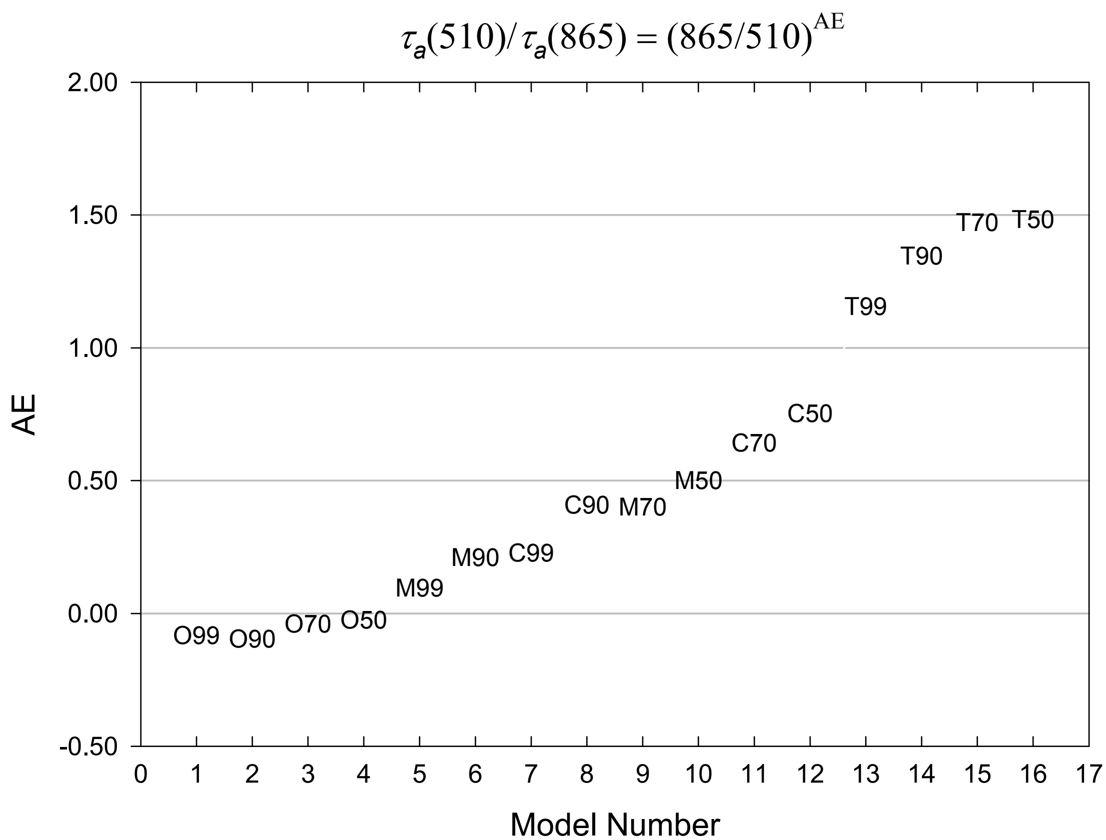



Figure 3. Relationship between MODIS aerosol model number and SeaWiFS Angstrom exponent (AE)

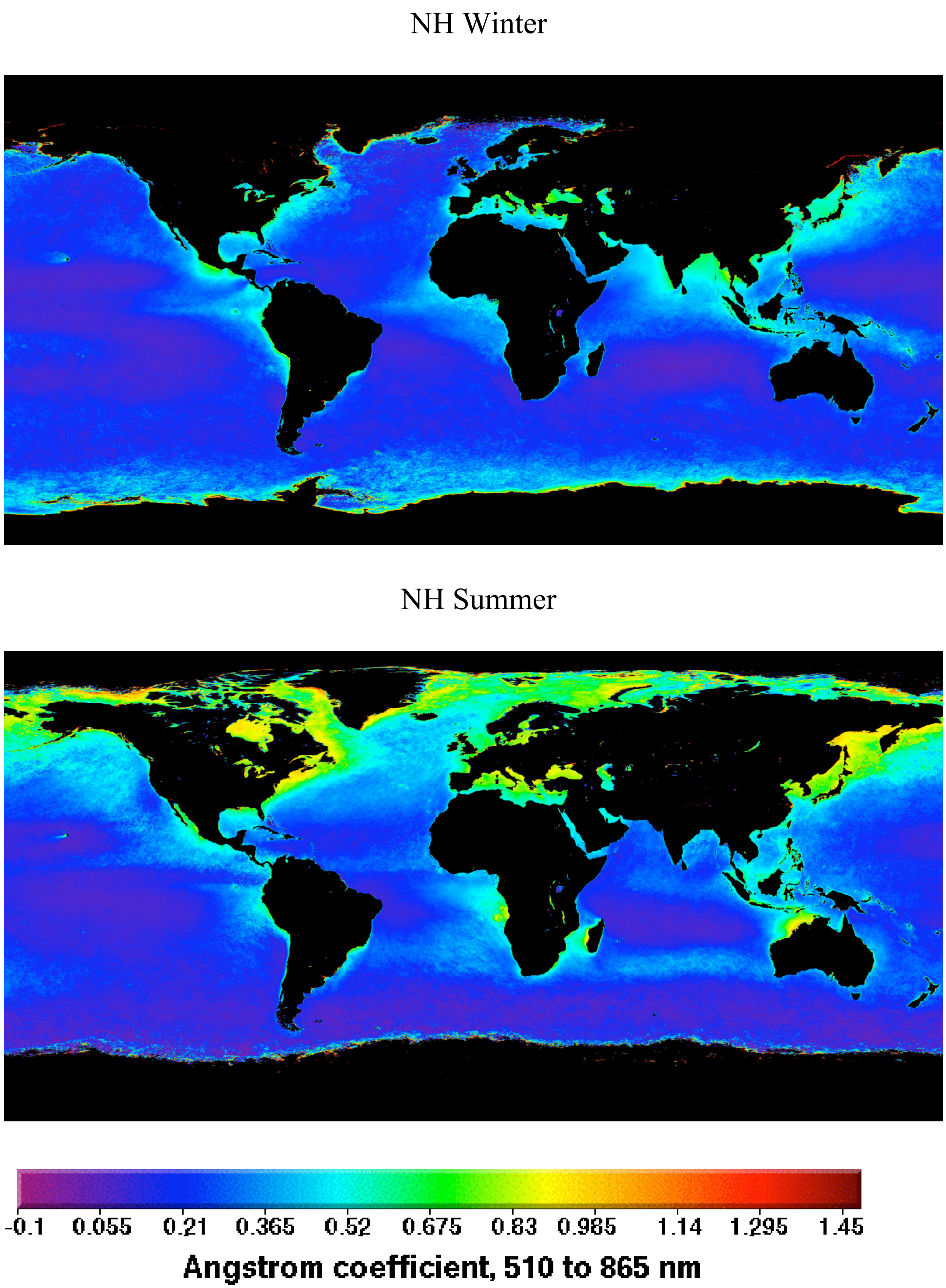



Figure 4 SeaWiFS 1998 -2002 in the Northern Hemisphere (NH) Summer and 1998-2003 in Winter.

The figure shows a clear seasonality in the model choices. The higher model numbers appear in the summer months in each hemisphere and the lower model numbers in the winter months. (Note that the variations in the two hemispheres are *exactly* out of phase.) In the equatorial Pacific there is very little variation in model choices throughout the year. The behavior that is seen in the three panels of Figure 2 is to be expected as the winds are higher in the winter producing more large-sized marine aerosol than in summer because of the presence of more breaking waves. The most meaningful way of describing the model number is to associate it with the Angstrom exponent of the aerosol (Figure 3). In the Northern Hemisphere winter, model numbers are in the 5-6 range corresponding to an AE of ~ 0.2, while in the summer the corresponding range is ~ 10-11, or AE ~0.5. In the Equatorial Pacific model number 6 is prevalent throughout the year. We compared these MODIS model choices with the SeaWiFS AE seasonally averaged over a 4 or 5 year period, shown in Figure 4. The tendencies seen in the AE's associated with the MODIS model selections are immediately evident in the SeaWiFS averages, i.e., higher values in the summer and lower in the winter in the respective hemispheres. Also evident is the near constant AE in the equatorial regions. The AE in the vicinity of Hawaii (but out of the island influence) is ~ 0.2-0.3 throughout the year suggesting MODIS models near 6 and 7 are very close to the SeaWiFS observations. However, it is important to note that the AE near the island is somewhat higher suggesting model numbers ~ 8-10, i.e., C90, M70, or M50. Such models are similar to those derived by Smirnov et al. [Maritime component in aerosol optical models derived from the Aerosol Robotic Network data, *J. Geophys, Res*. **108(D1)** 4033, doi:10.1029/2002JD002701, 2003]. They place the average AE for Lanai at ~0.5-0.6 suggestive of an aerosol model near M50. These results show that the MODIS aerosol model choice is in reasonable agreement with SeaWiFS and also with aerosol measurements on Lanai, suggesting that the relative calibration of MODIS bands 15 and 16 is adequate.

<u>Anticipated Future Actions</u>:

We will continue to work on validation of the atmospheric correction algorithms on Terra and Aqua.

### ***2. and 3. Algorithm Enhancements***

There are two important issues we are examining for inclusion into the MODIS algorithm: effecting atmospheric correction in the presence of strongly absorbing aerosols and/or Case 2 waters; and including the influence of the subsurface upwelling BRDF on water-leaving radiance.

*Strongly Absorbing Aerosols/Case 2 waters*

The first of the two enhancements we have been considering concerns absorbing aerosols. It also concerns Case 2 (coastal) waters, as strongly absorbing aerosols can be expected near the coasts due to urban pollution. Although success with SeaWiFS has shown that the MODIS algorithm performs well in ~ 90% of Case 1 water situations, it does not perform adequately everywhere; most notably in atmospheres containing strongly absorbing aerosols, or in turbid coastal waters that have high concentrations of all optically active constituents. Two important situations in which absorbing aerosols make an impact are desert dust and urban pollution carried over the oceans by the winds. In the case of urban pollution the aerosol contains black carbon and usually exhibits absorption that is nonselective, i.e., the imaginary part of the refractive index (the absorption index) is independent of wavelength. In contrast, desert dust absorbs more in the blue than the red, i.e., the absorption index decreases with wavelength. Generally, analysis of imagery contaminated by strongly absorbing aerosols require that atmospheric correction and water-constituent retrieval be carried out simultaneously. The same is true for Case 2 coastal waters. Because of the similarity of the algorithm requirements, we treat absorbing aerosols and Case 2 waters together.

Task Progress:

This task was "placed on the back burner" while working on the Terra/MODIS calibration described above. Previously, we applied (and validated) the spectral optimization algorithm [R.M. Chomko and H.R. Gordon, Atmospheric correction of ocean color imagery: Test of the spectral optimization algorithm with SeaWiFS, *Applied Optics*, **40**, 2973—2984, 2001] with the Garver and Siegel reflectance model ["Inherent optical property inversion of ocean color spectra and its biogeochemical interpretation: 1 time series from the Sargasso Sea," *Geophys. Res.*, **102C**, 18607—18625, 1997] in Case 1 waters. The results have now been published [R.M. Chomko, H. R. Gordon, S. Maritorena, D.A. Siegel, Simultaneous retrieval of oceanic and atmospheric parameters for ocean color imagery by spectral optimization: A validation, *Remote Sensing of Environment* **84,** 208—220, 2003]. We have now applying the spectral optimization algorithm to Case 2 waters and are trying to validate it for these waters using SeaWiFS data.

Anticipated Future Actions:

We will continue debugging the SOA code for MODIS imagery as well as the SMA code for use in windblown dust.

*The subsurface upwelling BRDF*

The subsurface BRDF issue involves relating measurements of the upwelled spectral radiance (used for bio-optical algorithm development, sensor calibration and product validation of all ocean color sensors) that are predominately made in the nadir-viewing direction (including MOBY data), with the water-leaving radiance at the remote sensor. The remote sensing viewing geometry is rarely nadir, thus an understanding of the difference between these two geometries is required, i.e., we need to understand the BRDF of the subsurface radiance distribution to reconcile these measurements. Our approach is to directly measure the BRDF as a function of the chlorophyll concentration and to develop a model that can be used for MODIS. In addition we are working on a specific algorithm for correcting the MOBY buoy data to address the BRDF effects at this location.

Task progress:

The current published state of the art for BRDF correction of ocean color imagery is the model put forward by Morel and coworkers (the latest version is Morel, Antoine, and Gentili, 2002, Bidirectional reflectance of oceanic waters: accounting for Raman emission and varying particle scattering phase function, *Applied Optics*, **41**, 6289 – 6306). This model is based on many of the individual particle optical measurements done over the years by Morel and his coworkers, but the BRDF model has not been validated in terms of its resulting radiance distribution except in limited cases (Morel, Voss, and Gentilli, " Bi-directional reflectance of oceanic waters: A comparison of model and experimental results", 1995, J. Geophys. Res., **100**: 13,143-13,150). Much of our effort in recent years as been directed towards collecting an accurate data set using the RADS-II and in the past year, the NuRADS radiance distribution camera systems. We are now at the point that we can really work on validating models and if necessary building more accurate models.

In our tests to date, the Morel, Antoine, and Gentili model has actually worked fairly well and the agreement with our data set has been good. Because of this, and to help separate geophysical variations from MODIS calibration issues, we have worked with Dr. Bob Evans and his group to implement this model into the new MODIS operational code, which will be used in the upcoming reprocessing. To see how this code can affect the measured radiance we can look at several special cases for the MODIS terra sensor. Because MODIS Terra views at nadir in the scan center, the orbit is slightly tilted, and it is a pre-noon equator crossing, the MODIS scan line will at certain times of the year view directly along the principal plane (the plane containing the solar direction and nadir). The geometry of the MODIS scan relative to the solar geometry varies throughout the year in a somewhat complicated manner, but in a single day the geometry of each individual point in a swath is repeated, thus if the water properties were the same, the BRDF correction factor would be similar for all swaths in that day. In Fig. 5 we show the BRDF corrections for 3 days through the year, day 120 (spring), day 169 (summer) and day 344 (winter) for 3 chlorophyll levels (0.03,0.3, and 3 mg/m3). Note that the BRDF is dependent on both viewing and solar geometry and the optical properties of the water. The BRDF is also dependent on wavelength, so three wavelengths will be discussed, 412nm, 490 nm and 560 nm. What is shown in the graph is the percent difference between Lnadir and the satellite view (Lview-Lnadir)/Lnadir*100. To get an idea of the relative geolocation of the swath, North and South America is shown alongside the swaths. At low chlorophyll this factor ranges from slightly negative (just east of nadir), to about 15%. Because the orbit is not perpendicular to the equator, the Northern Hemisphere and Southern Hemisphere are not necessarily symmetric. At higher Chlorophyll levels (3 mg/m3) there is much more absorption in the water, and this factor ranges over a larger spread (0-25%). Figures 6 and 7 show the factor for the other wavelengths.

To see the spectral variation somewhat more clearly, the next two figures (Figure 8 and 9) show the ratio of the correction factor (Lview/Lnadir) at two wavelengths. For low

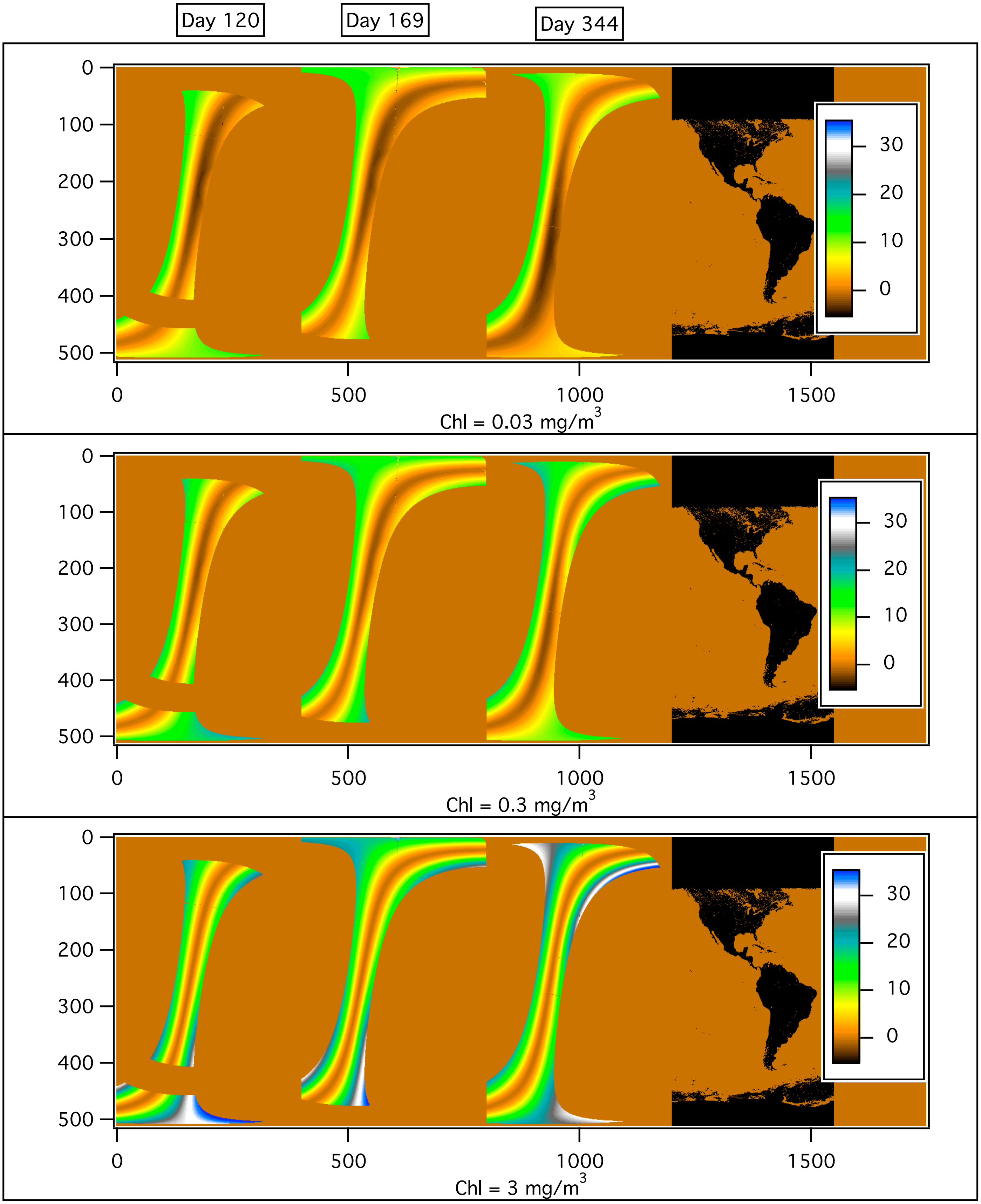



Figure 5. BRDF correction factor for 412nm, derived from Morel, Antoine, and Gentili (2002) with the MODIS scan geometry. Swaths for three different times of the year are shown (date listed at top of figure), while each panel represents a different chlorophyll level. The value shown is 100*(Lview-Lnadir)/Lnadir.

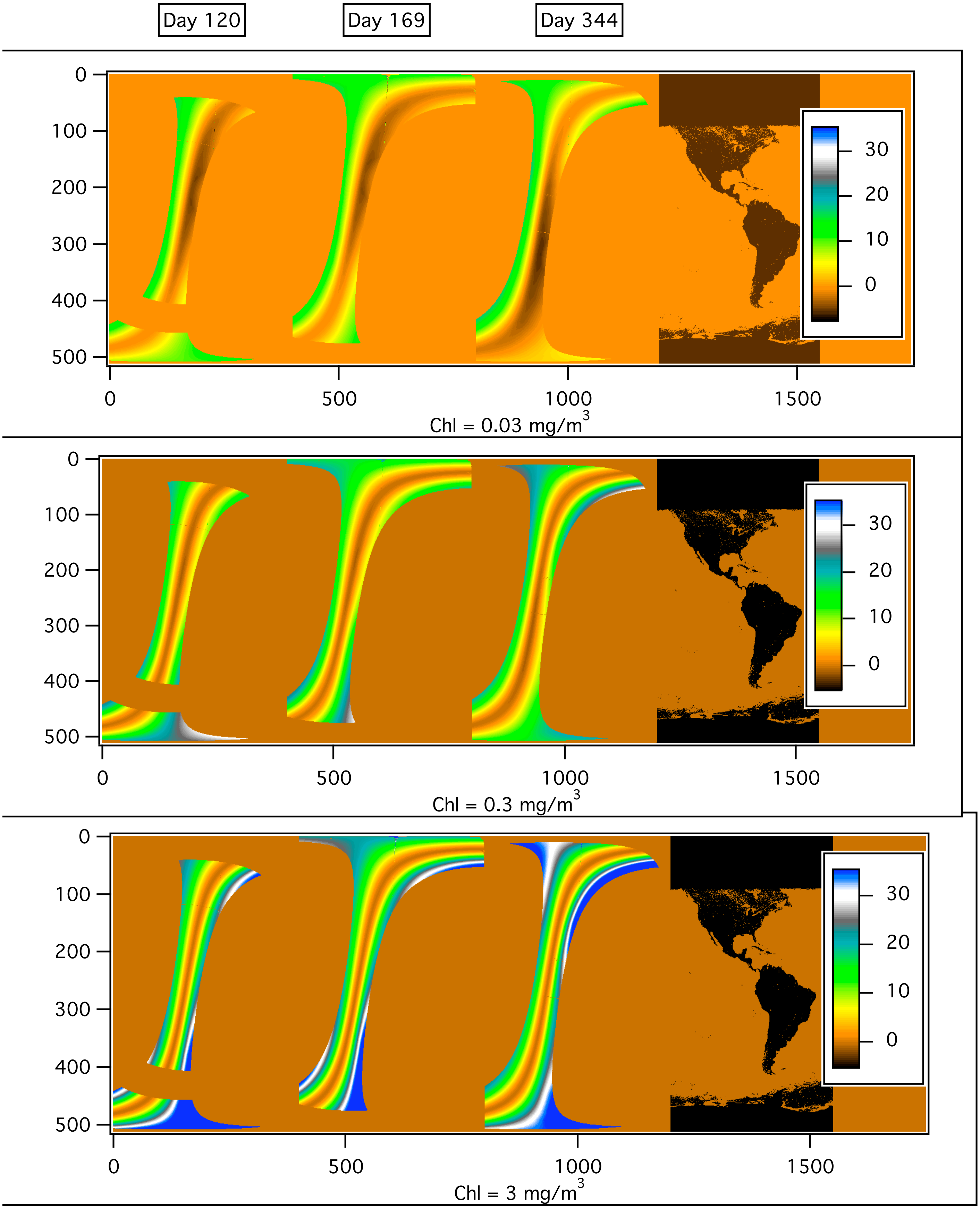



Figure 6. BRDF correction factor for 490nm, derived from Morel, Antoine, and Gentili (2002) with the MODIS scan geometry. Swaths for three different times of the year are shown (date listed at top of figure), while each panel represents a different chlorophyll level. The value shown is 100*(Lview-Lnadir)/Lnadir.

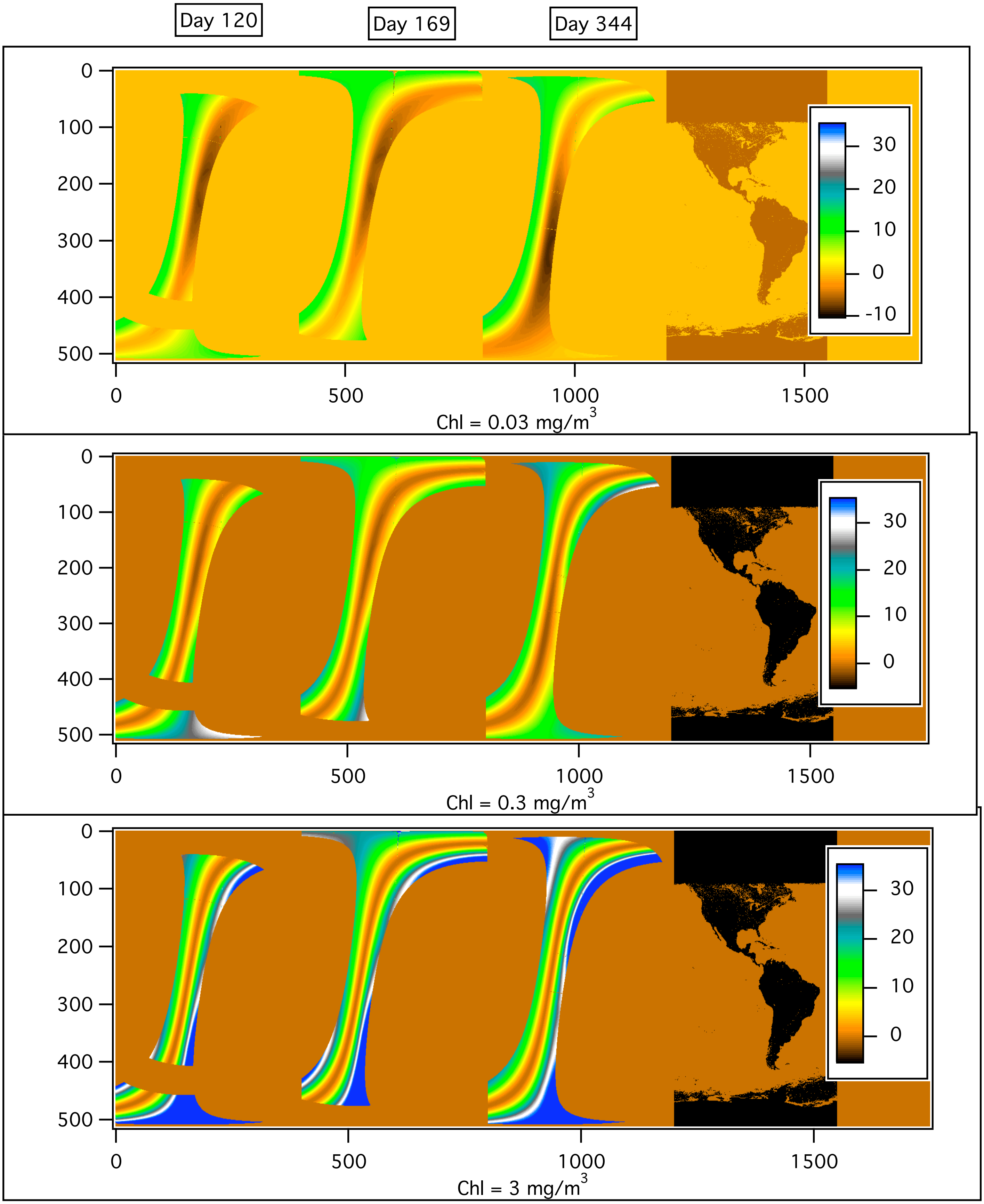



Figure 7. BRDF correction factor for 560nm, derived from Morel, Antoine, and Gentili (2002) with the MODIS scan geometry. Swaths for three different times of the year are shown (date listed at top of figure), while each panel represents a different chlorophyll level. The value shown is 100*(Lview-Lnadir)/Lnadir.

chlorophyll and 490/412nm, the correction factor is almost the same at the two wavelengths, thus a ratio of satellite viewed radiances would be independent of geometry. This is not surprising since at low chlorophyll levels the optical properties are not vastly different between these two wavelengths. However at higher chlorophyll's the ratio can be greater than 1.1, thus a 10% difference in the ratio of satellite viewed radiances versus nadir view. When looking at the ratio of 560/412 nm, at low chlorophyll's the ratio is also close to one except on the eastern edge of the scan. At higher chlorophylls the ratio increases to 15% or more.
The end result of this is including the BRDF can have a significant effect on the satellite retrievals and the calibrations. Including this in the processing stream has greatly improved the characteristics of the MODIS nLw products.

Anticipated Future Actions:

We will be continuing our efforts at validating the BRDF algorithm based on Morel, Antoine, and Gentili, 2002, and will be working on improvements to this algorithm.

## Validation of MODIS Algorithms and Products

### *4. Participate in MODIS Initialization/Validation Campaigns*

This task refers to our participation in actual Terra/Aqua/MODIS validation/initialization exercises.

Task Progress:
We participated in 3 field excersizes during the last 6 months, a MODIS/MOBY cruise (L89), in Hawaii during January, a algorithm development cruise in the Chesapeake in May, and another algorithm development cruise in Hawaii in June.
The MODIS cruise, L89, in January was mainly aimed at helping during the MOBY exchange and collecting radiance distribution data. We also hoped to acquire some Aqua/MODIS calibration validation data. However the weather was not very good for these efforts, so while we were able to help in the mooring switch out, we did not get a lot of data. However we left the instrument for a member of Dennis Clark's group to use and he was able to collect some data.
The cruise in the Chesapeake was directed towards obtaining data in much more turbid environments. We were able to collect 2 days of data in very turbid waters, but for the most part the weather did not cooperate during the 2 weeks. The Northeast had a very wet spring and this did not help our efforts, however we did get two sunny days. This combined with our measurements last fall should help us to get a start on the radiance distribution in turbid environments.
Finally we worked for several days on a small boat in Hawaii, collecting radiance distribution data, chlorophyll, and AC-9 data. During this cruise we concentrated on collecting data over a long period, from 1 hour after sunrise until mid-afternoon, depending on cloud cover. We also left the NuRADS instrument in place and functioning for use during another cruise in July.

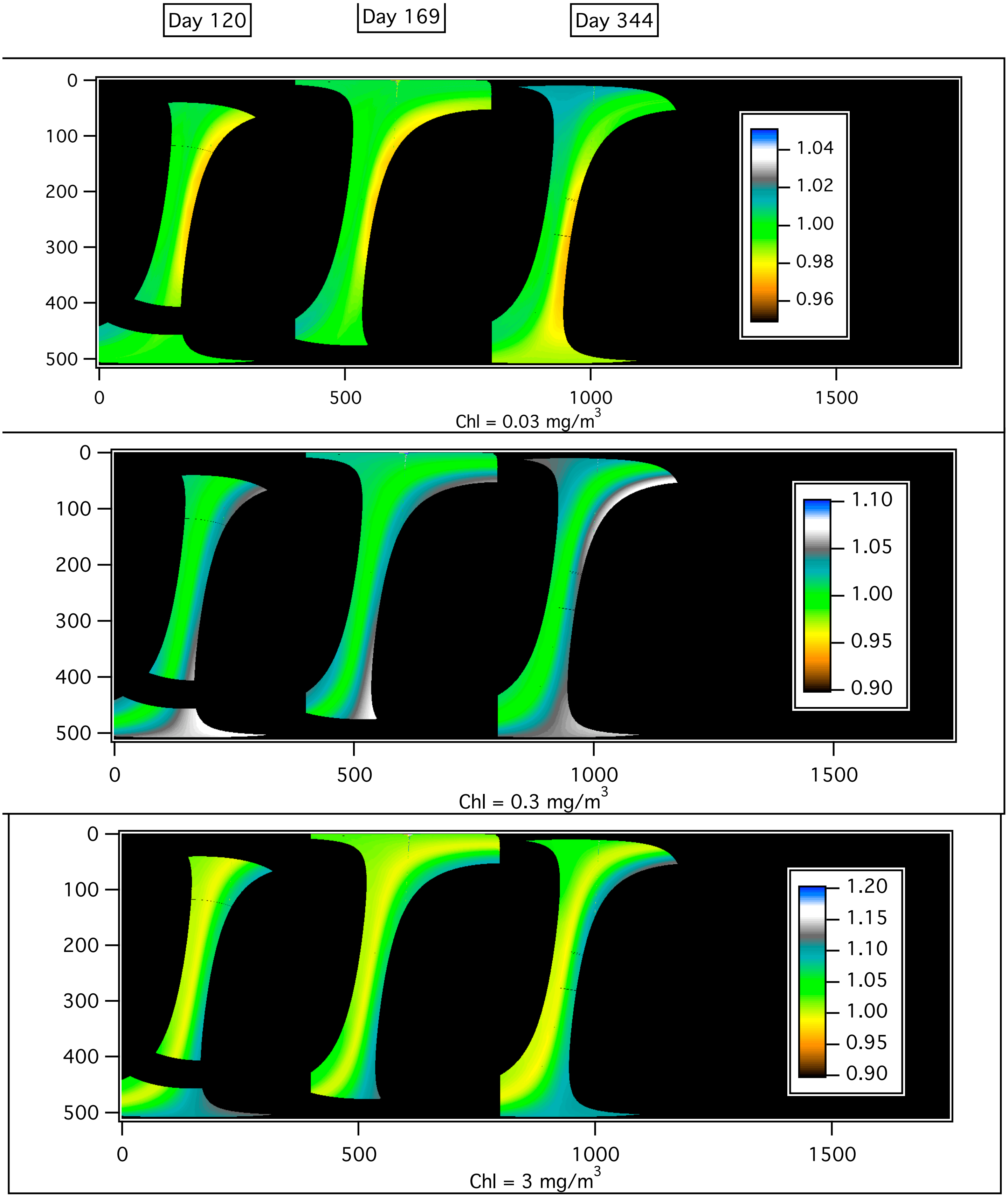



Figure 8. Ratio of BRDF correction factor for 490/412nm, derived from Morel, Antoine, and Gentili (2002) with the MODIS scan geometry. Swaths for three different times of the year are shown (date listed at top of figure), while each panel represents a different chlorophyll level.

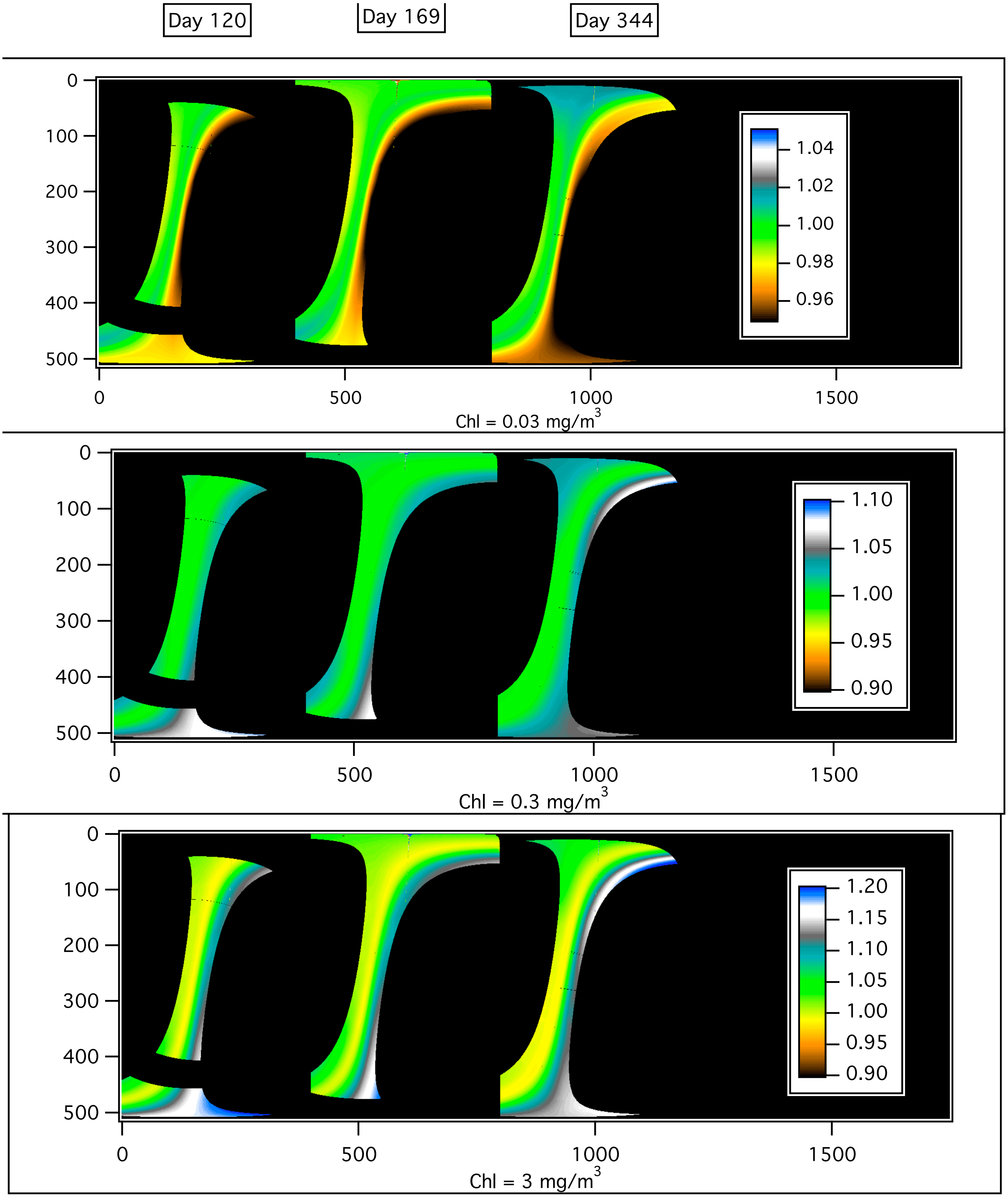



Figure 9. Ratio of BRDF correction factor for 560/412nm, derived from Morel, Antoine, and Gentili (2002) with the MODIS scan geometry. Swaths for three different times of the year are shown (date listed at top of figure), while each panel represents a different chlorophyll level.

The purpose of all of these cruises was to collect more radiance distribution data in both clear waters and turbid waters. Several factors combine to make it time-consuming to collect this data. The main features are that the radiance distribution is dependent on sun angle, so data must be taken in a wide range of sun angles, and also the instantaneous radiance distribution depends on the specific surface (waves) thus to make a data set relevant to a satellite which averages over a large area, many individual measurements must be averaged together. Thus we need many cruises to get a useful data set. We have also just finished an optical redesign of the NuRADS system, which enables much better data to be obtained at larger nadir angles. We are currently collecting data with this new design.

Anticipated future efforts:

The NuRads instrument is going to be used by Dennis Clark's group during field work performed in July. In addition we are planning on participating on another clear water cruise during November.
In addition much of the coming period will be spent reducing and analyzing the data obtained during our recent field campaigns. This is the last period of the contract so we will be finalizing the data analysis for many of our data sets.

**RETRIEVAL OF DETACHED COCCOLITH/CALCITE CONCENTRATION MOD 23**

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This last half year of work has focussed on several areas: 1) acquisition of new Gulf of Maine validation samples for MODIS-Terra and MODIS-Aqua validation, 2) preparation and participation in our June '03 chalk-ex cruise aboard the *R/V Endeavor*, 3) revision of a manuscript on optics and hydrography of the Gulf of Maine (which includes material on acid-labile backscattering from PIC), 4) revision of a new manuscript for a book chapter which includes a description of the MODIS PIC product plus our recently computed global views of surface PIC through the four seasons, 5) presentation of MODIS results at the Limnology and Oceanography meeting in Hawaii.

## Algorithm Evaluation/Improvement

Task Progress:

Much of our attention in algorithm evaluation has been directed to performing match-ups with the revised MODIS radiances (following reprocessing of all the MODIS-Terra data). Specifically, it has been essential to define the statistical accuracy of the MODIS PIC algorithm, as applied through 1 kilometer or binned data. We have continued a statistical analysis to estimate the standard error limits for the MODIS data, binned at different time and space scales. For 36km monthly averages, the standard error of the PIC estimates still is about 0.08ug PIC $L^{-1}$, well below typical background PIC levels

## Validation of MODIS Algorithms and Products

As coccoliths and suspended PIC (particulate inorganic carbon or calcium carbonate) are new products, and as Terra was only launched in December 1999 and Aqua launched in May '02, there are relatively few data sets available for validation, particularly for the coccolith and suspended calcite products. This is because coccolith concentration (PIC) is not frequently measured at sea, while chlorophyll concentration is. In conjunction with our NASA SEAWiFS activities, much of our validation estimates come from the Gulf of Maine, the site of frequent blooms of coccolithophores, and a region readily accessible from our laboratory.

*Validation of regional PIC*

During 2002, we acquired 108 new PIC samples from our Gulf of Maine ferry studies. These have been processed. Coccolith samples were taken at the same 108 stations, and those tedious microscope counts have been completed. Data from these counts still needs to be tablulated into spreadsheets. Parallel PIC samples and coccolith counts have been taken in order to check the coccolith-to-carbon conversion which is implicit in the MODIS two band algorithm. We have demonstrated using previous data that satellite-derived normalized water-leaving radiances are statistically correlated to the absolute PIC concentration, accounting for as much as 40% of the variance. Moreover, the nLw's are even better correlated to the coccolith concentration; coccolith concentration accounts for just over 50% of the variance in nLw's in the blue and green wavelengths.

*Chalk-Ex*

Another aspect of algorithm validation has been the June '03 Chalk-Ex experiment. For this experiment, we used Cretaceous coccolith chalk from the U.K. (with a median particle size identical to Emiliania huxleyi coccoliths) to make two patches, approximately 2 km x 1 km in size, which could be viewed by MODIS Terra or Aqua. The patches had sufficient calcite to provide concentrations equal to a typical bloom (but over negligible area as compared to typical coccolithophore blooms). The logistics for this experiment were significant as all the chalk had to be imported. The cruise began on 11 June and finished on 23 June, 2003. The two patches were made under mostly clear skies, and MODIS Aqua viewed both. We are still analyzing the MODIS TERRA data for the patches. In order to have finer-scale resolution patch views to compare with the satellite data, high altitude photography of the patches was also made. These data are still being analyzed and plotted on standard latitude/longitude maps. We also coordinated with the astronauts aboard the international space station to take photographs of the area during the experiment. As of this writing, those images have not been down-loaded from the space craft. All Chalk-Ex data from our Nov' 01 cruise have been processed, and worked-up. Presentations on various aspects of this work were given during the first half of this year.

<u>New validation data</u>

Gulf of Maine cruises aboard the M/S *Scotia Prince* ferry resumed in early May of 2003. To date, this year's trips have been under clear skies, maintaining our record of clear sea-days for satellite validation. Combined with last year's work, of our last 27d at sea in the Gulf of Maine, 26 have been under clear skies with at least one clear satellite overpass per trip.

<u>Validation of global PIC and coccolithophore pigment data</u>

*Cautions when using coccolith/PIC data products*

The coccolithophore data products are "provisionally validated", given that we have defined the RMS error based on ship validation measurements, under a wide range of PIC concentrations, using the collection 4 re-processed data. We nonetheless caution using these data from shallow ocean regions, particularly near carbonate banks (e.g. Grand Bahamas), where bottom reflectance will appear as a high-reflectance coccolithophore bloom (presumably such pixels would be flagged due to their shallowness). Moreover, near river mouths and in shallow waters, resuspended sediments (of non-calcite origin) may appear as high suspended calcite concentrations.

Only use these data if the waters are sufficiently deep to not have such bottom resuspension or direct river impact. Beware that MODIS-derived coccolith concentrations assume that the coccoliths are from the Prymnesiophyte, *E. huxleyi*. If this is not true, then inaccuracies will increase although the errors are not expected to be large. Even when using the data in units of mg $m^{-3}$, they nevertheless assume a constant backscattering cross-section for *E. huxleyi*, which is known to vary with the size of the calcite particle.

*Web Links to Relevant Information*

The algorithm theoretical basis document for the coccolithophore products can be found at: http://modis.gsfc.nasa.gov/MODIS/ATBD/atbd_mod23.pdf

More information about the algorithm and inputs can be found in:

Esaias, W., et al., 1998, Overview of MODIS Capabilities for Ocean Science Observations, *IEEE Transactions on Geoscience and Remote Sensing*, **36**, 1250–1265.

Anticipated future efforts:

Our future efforts will be:

4. Work-up of the results from the Gulf of Maine during 2002.

5. Continued sampling for PIC validation in the Gulf of Maine in ’03 (9 more trips will be scheduled for clear-sky days)

6. Final revision of book chapter for the new Springer book on coccolithophores (which includes a discussion of the MODIS algorithm and global results) .

7. Required revisions for our submitted paper on the Gulf of Maine results.

8. Further write-up of our Gulf of Maine results and PIC algorithm results

We have two more papers in preparation on the Gulf of Maine results. We will also begin a paper on the PIC algorithm and its performance.

9. Processing of data from our June ’03 Chalk-Ex experiment, specifically comparing the MODIS-derived results with the shipboard estimates of PIC concentration.

*Referencing Data in Journal Articles*

Results derived from this algorithm should cite the paper of Gordon et al.(Gordon et al. 1988) for the original discussion, and (Balch et al. 1996; Balch et al. 1999) for field data on the backscattering cross-section of calcite.

Citations

Balch, W. M., K. Kilpatrick, P. M. Holligan, D. Harbour, and E. Fernandez. 1996. The 1991 coccolithophore bloom in the central north Atlantic. II. Relating optics to coccolith concentration. Limnol. Oceanogr. **41:** 1684-1696.

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## Additional Developments

### Presentations (2003)

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### Publications (2003):

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Antoine, D., A. Morel, **H.R. Gordon**, **V.F. Banzon**, and R.E. Evans, Retrospective processing of the CZCS archive (1979-86) as a basis for analyzing satellite ocean color observations in search of long-term trends. I: Revised algorithms, sensitivity analyses and calibration considerations, *Global Biogeochemical Cycles* (Submitted).

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